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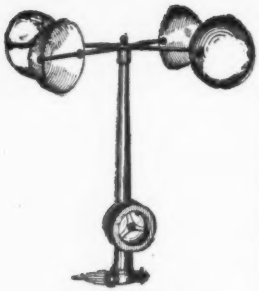

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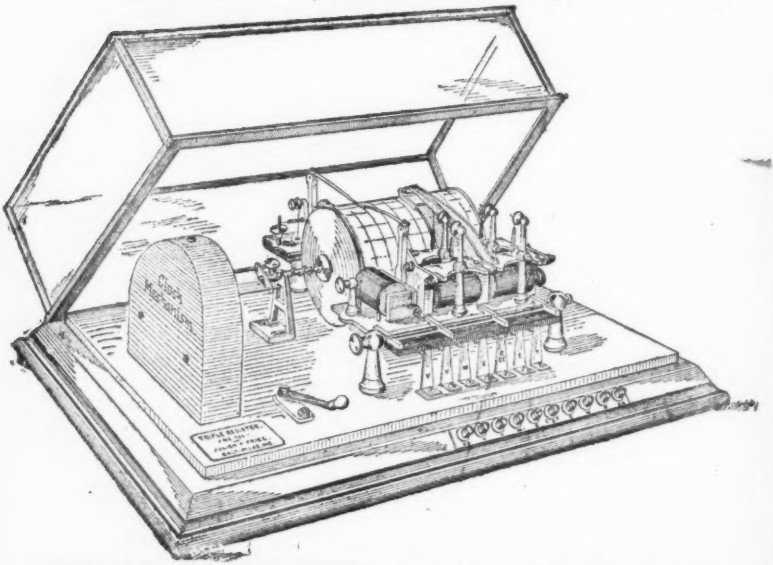

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THE AMERICAN

METEOROLOGICAL JOURNAL.

VOL. X. BOSTON, MASS., OCTOBER, 1893. No. 6.

# THE SEICHE IN AMERICA.

E. A. PERKINS.

SOME recent experiments of a fellow-student, Mr. S. M. Ballou, of the class of 1893 of Harvard College, brought to the author's attention the need of a collaboration of the work done on the seiche in America. Though the seiche has been carefully investigated in Switzerland, it has not received the attention it deserves in this country. In the following pages I have tried to present the subject in as clear a light as possible, hoping that by means of this brief essay I may awaken a wider interest in so curious a matter.

The *seiche* as defined by Forel, the accomplished Swiss physicist, is "a movement of the water, rhythmical, isochronous, and of decreasing amplitude . . . the result of a disturbance in the atmosphere."* Lake oscillations may have one or more nodes of vibration, but Forel prefers to apply the name of seiche to the uninodal vibrations only. They are of two classes, — longitudinal and transverse seiches; and of three orders: seiches with one node, with two or more nodes, and mixed seiches, — a compound of the others. In a preface to his study of the seiche, Forel has given an account of the early work on the subject, from which I have compiled the brief account below: —

The seiches were first noticed or commented on by Fatio de Duillier in 1730 at Lake Geneva. He attributed them to the stoppage of the waters of the Rhone by the winds. Jallabert, in 1742, supposed that they were occasioned by a sudden increment in the lake waters produced by the melting of the snow

* F. A. Forel, Le Lac Leman. 1886. P. 16.

by the morning sun. Bertrand, who followed him, attributed the seiches to electrical disturbances, raising the waters of the lake, which in their retreat produced oscillations. H. B. de Saussure, in 1779, after admitting a part of Bertrand's hypothesis, adds: "I believe, too, that sharp and local variations in the pressure of the atmosphere can . . . produce the flow and reflux by occasioning unequal pressures on different parts of the lake."*

From 1802 to 1812, Vaucher devoted his attention to seiches. He published his results in a memoir of sixty pages, which was the most complete work up to that time.† After citing notes of several seiches, he concludes: "There are great or small seiches in all lakes; those in which the seiches have not been noticed have not been sufficiently examined. Seiches can occur at all seasons of the year and at any hour of the day, but they are more frequent in spring and in autumn. Nothing appears to have more influence on this phenomenon than the state of the atmosphere; the more constant it is, the fewer the seiches; but when it is variable, we have more of them. Though seiches are more abundant in spring and autumn than at other seasons, still they are quite noticeable in summer, especially at the end of the season, when the largest observed seiches have occurred. The maximum amplitude does not exceed five feet, and the maximum period (for Lake Geneva) does not exceed twenty minutes."

In the second part of the memoir above mentioned, Vaucher investigates the cause of seiches, and, after criticising the theories of his predecessors, propounds the explanation generally accepted to-day. He seeks for the cause of the oscillation in variations of atmospheric pressure. After showing that seiches coincide with considerable movements of the barometer, he considers the lake as in two parts, in one of which the barometric pressure diminishes, while in the other it remains constant or rises. The two parts are then unequally pressed upon by the atmosphere, and the water of the lake tends to rise in the region of the least pressure and to fall in the regions of greater pressure. If this disturbance of equilibrium suddenly occurs, a balancing movement ought to result, and a return to rest is only

* H. B. de Saussure: Voyages dans les Alpes. Neuchâtel, 1779, I., p. 12.

† Vaucher: Memoir sur les seiches du Lac de Genève, composé de 1803 à 1804. Memoires de la Société de Physïque de Genève. T. VI., p. 35.

obtained after a certain number of oscillations, growing more and more feeble.

The other investigators who have followed Vaucher have generally admitted his theory, among them being Studer, Meyer, and Favre, and finally that accomplished physicist, M. F. A. Forel, who has made an exhaustive investigation of the subject which seems to leave little to be desired.

His principal series of papers appeared in the "Archives des Sciences Physiques et Naturelles" of Geneva in the following volumes: —

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1874 | . | . | . | . | . | Volume | XLIX., | page | 24. |
| 1875 | . | . | . | . | . | " | LIII., | " | 281. |
| 1876 | . | . | . | . | . | " | LVII., | " | 278. |
| 1876 | . | . | . | . | . | " | LIX., | " | 50. |
| 1878 | . | . | . | . | . | " | LXIII., | pages | 113, 189. |

As these reports may not be accessible to all who take an interest in the subject, I have deemed it advisable to give a brief abstract of Forel's researches and reasoning.

On commencing work, Forel's first step was to institute a careful observation of the seiches. This was at first done by direct observation of the rise and fall of the lake, but in 1876 a registering lake gauge, or, as Forel terms it, a "*limnimetre enregisteur*," was established at Morges, on Lake Geneva, and shortly after another one was established by M. Plantamour at Sécheron, near Geneva.

The direct observations gave M. Forel the following conclusions which he published in 1874 (Archives, XLIX., p. 34). The amplitude of oscillation is not constant in the same seiche, or in the same locality for different seiches. The duration of a wave is not the same for the same locality, nor are seiches observed at different times and at different places equal. The oscillation of a body of water may be of two kinds, — progressive or stationary. Progressive oscillations may be caused by a body striking the water, or the regular action of the wind. The seiches have been claimed for both kinds of oscillation, but Forel's observations tend to show that the balancing stationary oscillation is the true one. The whole lake seems to be thrown into vibration at once, which would be impossible with a progressive oscillation.

In order to test the properties of stationary oscillations and

obtain further confirmation of this theory, Forel constructed a tank of two plates of glass 1.30 m. long and 0.395 m. wide. These plates were set in a wooden frame about 30 mm. apart, and the frame was mounted on a cleat underneath its centre of gravity to rock it. From experiments Forel obtained the following principles: —

The period increases with the length of the tank.

Up to a certain limit of depth, the period of the wave diminishes as the depth increases.

This limit of depth is sooner obtained as the basin is shorter.

The amplitude increases as the depth is diminished.

In a tank with sloping sides, the amplitude is greatest at the shallowest part, and least at the deepest.

The oscillatory movement is simultaneous in all parts of the tank.

These properties of the artificial stationary oscillation are those which the seiche has, hence M. Forel holds that the seiches are stationary, balancing oscillations.

In connection with these experiments of Forel, perhaps it would be well to introduce brief mention of some crude but satisfactory experiments made by the writer. I had at my disposal a glass tank, forty-five inches long, five inches wide, and seven and one half inches deep. My first efforts were to produce an uninodal seiche. This was not an easy thing to accomplish, and, after some experimenting, I adopted the following method: I took a thin strip of wood, the area of the tank, and floated it on the water; then, by pressing one end carefully, I obtained a good uninodal seiche. Small wooden partitions were used for shorter seiches, and an assortment of pieces of zinc enabled me to construct sloping bottoms and concave and convex shore slopes. Although I had some difficulty in making the partitions water tight, the experiments on the whole were quite satisfactory and fully agreed with Forel's results.

The paper of Vol. LIII. is essentially a local one, in which Forel cites his observations on the Swiss lakes as regards time, amplitude, and occurrence. The conclusions at the end are substantially those given at the end of the preceding paper, which are cited above.

In Vol. LVI., 1876, page 305, which does not properly belong with the main set of papers, Forel describes his "*limnimetre*

*enregisteur*," which he established at Morges. The principal features of the instrument are a well, two metres in diameter, with a subsurface outlet into the lake, and a basin floating on the water, inside the well, 80 cm. in diameter. The sides of the basin are covered with cotton to prevent errors from capillarity. The well is located a short distance out from the shore in the lee of a breakwater. The registering apparatus is of the ordinary construction, revolving at the rate of one millimetre per minute. This apparatus, Forel states, is so sensitive that the vibrations of a steamer are recorded at a distance of fifteen miles before and after the steamer's passage. Several tracings of seiches made by this instrument accompany the paper.

In Vol. LVII., pp. 278 *et seq.*, Forel discusses the period of the seiche. Dr. Frederick Guthrie studied in 1875 the movements of stationary oscillatory waves in experimental basins.* All of Guthrie's experiments are on the supposition that the water is of so great depth that the depth has no effect on the period, *i. e.*, of infinite depth. This occurs when the depth is half or more of the length. As the results of these experiments Guthrie lays down two rules : —

1. That binodal oscillations in a rectangutar tank are equal in period to those of a pendulum whose length is $2/\pi$ of the length of the basin.

2. The period of an uninodal oscillation in a rectangular tank is to that of a binodal oscillation under the same conditions as $\sqrt{2}$ is to 1.

According to this, the formula for uninodal oscillations in a rectangular tank is as follows: Let $t$ be the time of a half oscillation of the water, and $l$ the length of the tank, and $g$ = gravity, then

$$t = \sqrt{\frac{\pi l}{g}}$$

This formula of Guthrie would be applicable to seiches if the water of the lakes were deep enough, but the depth is too small in comparison with the length of the lakes to be neglected. However, M. J. Rud. Merian, of Basel, has made an exhaustive mathematical analysis of the movements of liquids,† and has derived an elaborate formula for the period of oscillations.

* Proceed. of Phys. Soc. London, 1875. VI. "On Stationary Liquid Waves."

† "Ueber die Bewegung tropfbarer Flüssigkeiten in Gefässen." Basel, 1828.

Forel has verified this formula experimentally in a small tank, and found results well within the limits of experimental error. He finds the formula holds for irregular basins if $h$ be taken as the mean depth. This mean depth is not easily obtained for lakes, so Forel obtains it from the formula by substituting values for $t$ and solving for $h$. A large number of examples are cited among the Swiss lakes where the mean depth thus obtained agrees substantially with that taken from the contour maps.

Sir William Thompson in a letter to M. Forel has shown how Merian's formula may be greatly simplified. When the ratio of depth to length ($\frac{h}{l}$) becomes a very small fraction so as to be negligible, the formula becomes: —

$$t = \frac{l}{(g\,h)^{\frac{1}{2}}} \left\{ 1 + \tfrac{1}{4} \left(\pi \tfrac{h}{l}\right)^2 \right\}$$

In almost all lakes the conditions are such that $\frac{1}{4} (\pi \frac{h}{l})^2$ can be readily neglected so that the formula becomes still more simplified: —

$$t = \frac{l}{(g\,h)^{\frac{1}{2}}}$$

This formula does not change appreciably the results obtained by M. Forel in his calculations for the Swiss lakes which he cites.

I continued the experiments, which were mentioned above, to cover the amended formula of Forel. A set of thin boards, whose lengths were as 1, 2, and 4, were employed with varying depths of the water, and partitions were applied to shorten the tank when necessary. The relation between length was very satisfactorily shown by taking time of ten seiches and comparing it with the time of ten seiches of half the length and of one quarter the length. This was repeated for several depths. The relation between depth and time was not as satisfactorily demonstrated, as the partitions were not water tight and did not hold very well for a good depth of water; but the results, when carefully examined, showed that the relation existed according to the formula.

Forel's next article ("Archives," LIX.) is strictly a local article, describing the seiches of the Swiss lakes. In Vol. LXIII. he considers the causes of the seiche, and shows that they are of atmospheric origin by the chain of reasoning which I have abstracted: —

Spontaneous movements of the lake are impossible.

The inflow of a large amount of water would only give a movement of slight duration and not a shock to the whole lake.

Phenomena of heat would only cause local currents.

If the seiche were caused by electrification of the water we should have extraordinary phenomena during thunderstorms, which is not the case.

The "breath of the avalanche," or wind caused by a land-slip, is certainly powerful enough to cause seiches, but no slips have been observed which were followed by seiches, and, furthermore, seiches do occur when there are no slips.

A careful study of seiches shows that they are accompanied by a constantly changing barometer.

A careful comparison of barometer and *limnimetre* records shows that seiches are always accompanied by violent storms.

Although earthquakes have been known to be accompanied by seiches, this happens but rarely; in fact, the tide-gauges have shown not the slightest trace of several sharp shocks in the immediate vicinity.

With this volume Forel ends his main series of papers. He concludes his essay with the following summing up of his work: —

Seiches are uninodal, stationary vibrations of lake water. They appear in the form of waves, which alternately raise and depress the water of the lake on each side of the nodal line of the oscillation.

There is no change on the node line; it reaches its maximum at the two extremities of the longitudinal diameter. They oscillate along the principal directions of the lake — longitudinal and transverse seiches. They manifest themselves by a series of waves of constantly decreasing amplitude from the first wave, which is the maximum. If a new series of oscillations is begun before the old series ends, the seiches are superimposed, giving a great variety and mixture of oscillations. Each series of seiches has its own sole generating impulse. These impulses may have come from the following sources: —

(*a.*) Rapid local variation of atmospheric pressure.

(*b.*) The relaxation of the wind, which has heaped the lake waters up to one side.

(*c.*) A gust of wind striking the lake obliquely.

(*d.*) Storms.

(*e.*) Electrical attraction (good in theory, but not appearing in practice).

(*f.*) Avalanche winds.

(*g.*) Earthquakes.

Of these, storms are by far the most frequent cause.

Forel's other papers are chiefly devoted to a restatement of his work in somewhat different form. Latterly he has done some work on an analysis of the records of his tide-gauge, resolving his mixed seiches into their component parts. But the limits of this paper will not allow a discussion of this, especially since a fellow-student, Mr. S. M. Ballou, is preparing a paper upon some observations of his at Lake Skaneateles, near Syracuse, N. Y., which will fully deal with this subject.

The seiche in America has been very little studied, although these oscillations have been noticed for many years. Prof. Joseph Le Conte, in 1884,* stated that, as far as he was aware, true seiches had never been noticed in any of the American lakes. He mentions, however, that changes of level of American lakes (including annual and tidal changes) have been studied by a number of observers whose names he gives.

Prof. Le Conte considers the seiche at some length, and predicts the period of uninodal seiches for Lake Tahoe, if such oscillations are ever discovered there.

The papers of these early observers, which Prof. Le Conte mentions, deal chiefly with the questions of mean annual and monthly change of level and those of lunar tides, and therefore are not pertinent to this paper. However, Prof. Mather and Col. Whittlesey have shown that lake oscillations take place when the barometer shows a decided movement, and that the wind is generally south before and northwest afterwards, showing the passage of a storm.† The observations cited do not show the existence of the long uninodal vibration, which is the main subject of my paper, but only some multinodal seiches. As the area of the Great Lakes is so large, the uninodal seiche would naturally be of infrequent occurrence, as a powerful blow must be struck on a comparatively large area to produce it.

* "Physical Studies of Lake Tahoe," Overland Monthly, January, 1884, p. 41 *et seq.*

† Smithson. Contrib., Vol. XII., 1854, p. 15 *et seq.*, "Fluctuations of Level of North American Lakes."

But this uninodal vibration does exist on the Great Lakes. Gen. C. B. Comstock states in the "U. S. Chief of Engineer's Report for 1872," p. 1040, that there is a wave constantly passing between Milwaukee and Grand Haven on Lake Michigan. The tide-gauges show that there are eleven great waves per day at each of these places, and the waves have a period of a trifle over two hours This, Gen. Comstock says, would correspond to the passage of a wave, according to the formula quoted above. Taking the mean depth between Milwaukee and Grand Haven as 400 feet and the distance as 85 miles, $t = \frac{85 \times 5280}{60 (400 \times 32\frac{1}{2})} =$ 66.115+ minutes for a half-seiche and 132.230+ minutes, or 2 h. 12 m. for a complete vibration, which is the period assigned to it by Gen. Comstock.

A tracing of the tide-gauge at Grand Haven, Mich., for the month of April, 1893, forwarded to the Geographical Laboratory of Harvard College through the kindness of U. S. Ass't. Engineer L. H. Goddard, shows this two hour and twelve minute period with great exactness. Every day in the month this period can be distinguished, although on some days it is almost obliterated by minute seiches, or "embroidery," while a crest is often marked by another superposed seiche in stormy weather; but the succeeding crest appears after the two hour period.

Simultaneous records of tide-gauges were taken along the Lakes for many years, and these records are now stored in the Army Engineer's office at Washington, where they may presumably be examined by competent students, under permission from the Chief of Engineers.

In his report for 1872, Gen. Comstock cites some remarkable seiches observed by Major Wilson at Oswego. The first one occurred on June 13, 1872. Its period was from twenty to thirty minutes, and during its continuance a white squall passed to the north, over the lake, accompanied by a small waterspout. An employee of the Survey, who happened to be out on the lake, reported that he heard strange noises, bubbles came to the top of the water, and the fish rose to the surface as if stunned. Major Wilson's report is accompanied by barometric and water-level curves. Major Wilson again cites the seiche of July 19, 1873 (Report for 1873). It was very much like the first, the most remarkable feature being a fall of one foot of water in five minutes.

Thus far the subject has had a scientific bearing alone. To show, however, that the subject deserves attention, if only from a practical point of view, I append the following clipping from the *Marine Record*, of Cleveland, Ohio, for April 13, 1893: —

"Tide Wave at Chicago.

"On Friday morning last (April 7, 1893), the port of Chicago was visited by a tide-wave, bore, a phenomenon called seiches, or, in plain terms, a sudden vertical motion of the water in the southern portion of Lake Michigan; for it appears the wave swept over the beach at St. Joseph, Mich., seven hundred feet back from the high-water mark, the vertical rise at that point being given as four feet, a report which is duly authenticated from Chicago. At the latter port a recurring wave, which also characterized the St. Joseph phenomenon, caused great damage to shipping and called forth the assistance of tugs and port officials to secure the disabled vessels broken adrift through the force of the tidal wave. . . . There is ground for study in deciding whether . . . the seiches are capable of being forecasted by the local forecast officials at lake stations a few hours in advance of their origin."

Upon receipt of an account of this seiche, I corresponded with several of the city engineers and postmasters along the lake, in order to obtain as full an account as possible of this phenomenon. The following extract from a letter of H. C. Frankenfield, Local Forecast Official at Chicago, will perhaps give a good idea of the weather conditions there on April 7, the date of the above-mentioned seiche: —

"High winds commenced about 2.30 P. M. April 6, blowing steadily from the S. E. until 1.30 A. M. April 7, when they shifted to N. N. E., blowing from that quarter until 4 A. M., when they again went to S. E. The velocity varied from thirty miles per hour at 2.30 P. M. April 6, to forty-three miles per hour at 1.50 A. M. April 7.

"The wave occurred between 1.30 A. M. and 1.45 A. M. April 7, and its height was from four to six feet. The damage done was principally to vessels anchored in the river. Several were torn from their moorings and carried toward the lake, causing numerous collisions with other vessels. Some were carried out into the lake. I do not think the wave was preceded by smaller ones, but, judging from the barometric oscillations after the principal wave, there must have been several smaller ones during the next two hours. These waves occur from time to time, and I have observed that they always occur at the time of a sudden and decided rise or fall in the barometer."

The barograph tracing which accompanies Mr. Frankenfield's letter shows a sharp rise in the pressure amounting to 0.13

inch at the time of the seiche. On comparison of this sheet with the barograph records at Milwaukee and on the steamer "Roanoke," which was about thirty miles east of Milwaukee at the time of the seiche, I find the same sudden rise of pressure occurring at the same time, and of the same amount, as that which was noted at Chicago. One important point deserves notice. At Chicago the barometer after this rise registered 28.80, at Milwaukee 29.20, and on the steamer "Roanoke" 29.95 inches. Capt. J. W. Martin, of this vessel, gives the following account of the storm: —

"On Thursday evening, April 6, at 9.30 P. M., the steamer 'Roanoke' left Milwaukee, bound for Grand Haven, eighty-five miles due east from point of departure. It was then blowing fresh from the southeast, with wind velocity of twenty-five miles per hour accompanied by rain, with a heavy sea running from a south and south-east direction. At 10.30 P. M., I noticed that the sea was running very irregular; at times there would be scarcely any, followed by several unusually heavy seas. About this time the wind began to shift to the eastward, when it began to rain furiously, accompanied with heavy thunder and lightning. At 11.30 P. M. the wind had worked around to the northeast, and was blowing about forty miles an hour, although the sea continued running from the southeast. At 11.45 P. M. the wind suddenly shifted to the northwest, and blew a furious gale for about ten minutes, accompanied with terrific thunder and lightning, followed by heavy rain. This suddenly ceased when there followed an entire lull in the wind, with the sea very much broken up, although still running principally from south-east. The clouds were very dense and seemed to be nearly stationary, very low down. We were then about twenty-five miles east of Milwaukee. These conditions remained in force until 12.30 A. M. April 7, varied by an occasional display of lightning, with heavy thunder, and sudden shifting of the wind to almost every point of the compass.

"At 12.30 A. M. the temperature began to fall perceptibly; and within a few minutes it was blowing hard from the northeast, where it continued for the balance of the night. We did not arrive at Grand Haven until 9 A. M. of the 7th. Shortly after the wind shifted to the northeast, at 12.30 A. M., a sea began to run from the northward, at the same time that the old sea from southeast was still running, producing rather a disagreeable disturbance or wave motion."

From the above accounts, it is evident that an extreme low-pressure area was over the southern end of Lake Michigan about 1 A. M. on April 7. This was accompanied by a heavy thunder-storm, which passed over the lake at that hour. The sudden rise of the barometer was probably the reactionary downward

pressure which precedes the storm, and this was the generating impulse which set the lake in motion.

From other points on the lake I have received the following records: at Saugatuck, Mich., a rise of four feet; at South Haven, a rise of three feet; at Waukegan, Ill., four feet eight inches, and at Grand Haven, Mich., a rise of about three feet. Changes of level are reported at Racine, Milwaukee, and other points along the lake The tracing of the record taken by the tide-gauge at Grand Haven shows that this seiche was not uninodal, although a set of uninodal vibrations seems to begin with the rise of the water.

One thing worthy of notice is the discrepancy between the amount of the downward atmospheric impulse and the rise of the lake. Fifteen hundredths of an inch of mercury would equal about 0.15 feet of water, and this amount of extra pressure certainly does not correspond with the four and five foot seiches reported at different points. The most reasonable explanation of this phenomenon, I think, would be to regard it as a bore, or "mascaret," produced in a small lake-wave as it advances towards a gently sloping shore. The reader will recall that Forel found this in his experimental tank. This question of bore, however, is one that demands further study.

Mr. Wm. Pierson Judson, of Oswego, N. Y., writes me that on the afternoon of April 7, about 6.20, the water of Lake Ontario rose suddenly about two and one-half feet while a thunderstorm was observed over the lake, passing to the north. This is probably another effect of the cyclone which was passing over the Lakes at that time.

I have received accounts of several minor seiches on the Great Lakes, but nothing that will bear comparison with the great seiche of April 7, 1893. This seems to be one of the largest oscillations ever observed on the Lakes. It is to be regretted that synchronous observations of this phenomenon were not taken by tide gauges at different points on the shore.

As to the forecasting of seiches, this cannot be done with accuracy until we obtain further knowledge of the bore, and ascertain by more numerous barographs the advance of sudden changes in the pressure of the atmosphere. But a great deal of useful information may be obtained by anyone who has the patience and the opportunity to search out of the great mass of

material now lying in the Army Engineer's office in Washington, the synchronous observations along the Lakes, and the weather conditions corresponding to them.

HARVARD COLLEGE, CLASS OF 1894.

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## THE HAIL STORM OF MAY 20, 1893.

PROF. FRANK W. VERY.

ON the afternoon of May 20, 1893, southeastern Ohio, southwestern Pennsylvania, and the northern part of West Virginia, were visited by thunder and hail storms of uncommon violence. Throughout a large part of this area there was more or less hail, which, along the river valleys, became in some places phenomenal. In the neighborhood of Pittsburgh, and at various places along the Ohio River, balls of ice from an inch and a half to two inches in diameter fell for about five minutes, breaking tens of thousands of dollars' worth of glass, and in the city streets driving horses frantic. For weeks after the storm there could be seen, in soft earth, pits about an inch and three quarters in diameter, and from a half to three fourths of an inch deep, distributed with tolerable uniformity from four to six inches apart, due to the impact of the hail, while painted houses and metal roofs still show abrasions and dents which witness the force of the blows.

Mr. Henry T. Weed, assistant in the Chemical Laboratory of the Western University of Pennsylvania, measured the water from the melting of thirty hailstones of the larger size,— not the very largest that could be found, but such as could easily be duplicated by hundreds,— and obtained 1112 c. c., or an average volume of 37.1 c. c., corresponding to a sphere 4.14 cm., or, 1.63 inch in diameter.

The majority of the hailstones being oblate spheroids, the largest diameter was in general a little greater than this or about $1\frac{3}{4}$ inches.

The largest recorded diameter which has been communicated to me is by Mr. Thomas Langford, an engineer of Allegheny, Pa., who obtained $2\frac{1}{2}$ inches by caliper measure, with a variation of not over $\frac{5}{1}\frac{1}{0}$ inch in any part. Spherical stones of this size

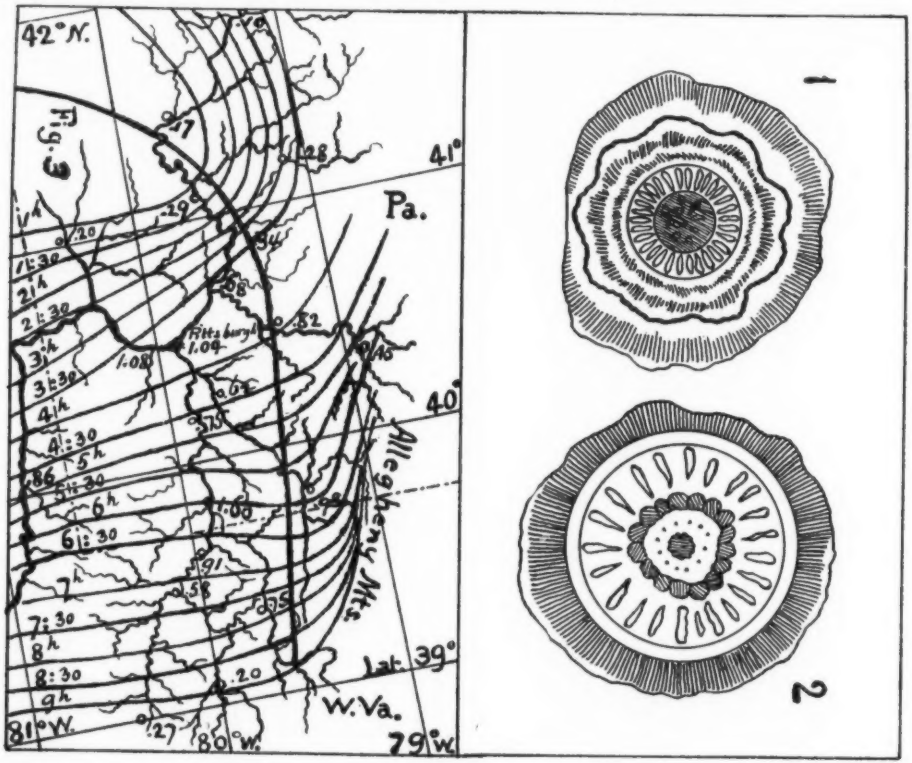
fell in his neighborhood perhaps six feet apart, the common stones of about 1¾ inches being 6 inches apart. He also saw, but did not measure, flattened disk-shaped hailstones which he estimated to be 3½ inches in diameter. Glass ⅜ of an inch thick, in plates 16 inches wide, was broken by these greatest stones, although resisting the more numerous impacts of the smaller ones, which were still capable of making dents ½ inch deep in $\frac{1}{10}$ inch iron plates.

Figs. 1 and 2 are sections of two hailstones which I picked up on my return to Allegheny, two hours after the storm. Their external dimensions had undoubtedly been largely reduced by melting, and it is possible that the radial bubblelike cavities were the result of an internal melting from local absorption of radiation similar to that which produces the beautiful ice flowers in homogeneous lake ice when penetrated by the sun's rays.

Prof. F. C. Phillips proved that, in all those cases examined by him, these inclusions in the solid ice were of liquid filling, by melting several hailstones rapidly in warm, clear water, when only an excessively minute air-bubble was set free from the small nucleus of snowy ice.

In the hailstone shown in Fig. 1, an opaque snowy nucleus, 0.20 inch in radius, was surrounded by a pellucid layer, 0.15 inch thick, containing numerous radiating liquid enclosures. This layer was terminated by a sharply defined boundary forming a nearly perfect sphere, 0.70 inch in diameter, surrounded by a layer from 0.20 inch to 0.30 inch thick, of wavy, marginal form, and composed of several irregular alternations of clear and opaque ice. The mammillated circumference suggests an adherence of numerous soft, snowy masses to a hard spherical stone, and the alternations indicate successive passages through layers of rain cloud and snow cloud. Outside of all were layers of pellucid and of snowy ice, increasing the diameter to about 1.75 inches where least melted.

In the section shown in Fig. 2, there was a central nucleus of snowy ice, 0.08 inch in radius, surrounded by a layer of clear ice from 0.10 inch to 0.20 inch thick, containing a few minute dots at the middle of its thickness. The circumference of this somewhat irregular zone was edged by small opaque mammillated projections, about 0.08 inch in diameter, beyond which was


42° N.
41°
40°
39°
Pa.
W. Va.
Allegheny Mts.
Lat.
81° W.
80° W.
79° W.
Fig. 3
Pittsburg
1.04
1.08
1.00
1
2

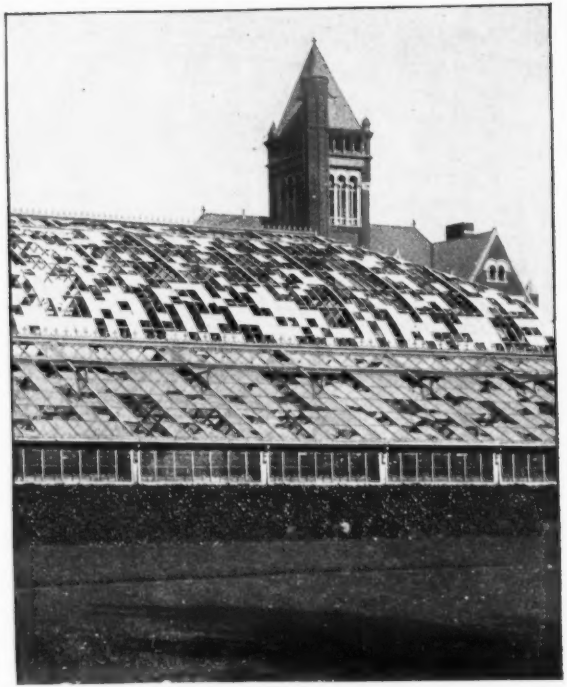


FIG. 4.

FIG. 5.

a clear zone 0.30 inch in thickness, containing large radially disposed liquid enclosures. These cavities were about 0.20 inch long, and perhaps 0.04 inch in diameter at the larger end, which was usually on the outside, the cavity tapering to a point towards the centre, although a few of the elongated bubble-like forms were square-cut at both ends. This zone was bounded by a thin line of opaque ice, followed by a clear layer 0.08 inch thick, and the whole enclosed by snowy ice at least 0.20 inch deep. The unmelted section must have been over 1.8 inches in diameter.

Dr. W. J. Holland, Chancellor of the Western University of Pennsylvania, has favored me with some sketches and descriptions of the hailstones, and also of the approaching storm clouds, as seen from Oakland, a suburb of Pittsburgh.

The sections were procured "by melting off opposite sides upon a warm plate." When reduced to a thickness of about one eighth of an inch, the sections were placed on carbon paper, bringing out the whole effect of the internal structure.

"The majority of them were oblately spheroidal in form, with a depression at one of the poles, which showed the clear translucent ice within the outer crust. From this depression ribbed rays of opaque ice radiated outwardly making a continuous crust with the small globular masses of opaque white ice which formed a continuous outer covering. The sections of the stones showed a nucleus of opaque white ice, from a quarter to three eighths of an inch in diameter. In a number of cases there was evidence of a whorled or spiral structure in the ice composing this nucleus. The nucleus was surrounded by a mass of clear translucent ice penetrated by longitudinal air cells, in appearance resembling the bubbles which are formed in clear ice when freezing downwardly upon the surface of still water. These bubbles radiated from the centre of the mass. They were, without exception, in all the cases I observed, rectilineal in their course, but in some instances the lines were interrupted, and consisted of a succession of small oval bubbles arranged in a rectilinear series, just as in ice formed in the ordinary way upon still surfaces of water.

"The diameter of these air vesicles was not uniform in all cases. They were rounded at their extremities, and in a number of cases the outer end of the vesicle was the largest, though in a

number they were largest in the middle. The larger end being so frequently near the periphery of the mass suggests to me that the process of freezing must have proceeded from without inwardly. The outer envelope, or crust of opaque ice which I have already described, seemed in some cases to be adherent to a thin inner crust of smooth opaque ice, which was separated from the outer crust by a very thin layer of clear ice. The formation of these masses in the upper air is necessarily a matter calculated to provoke inquiry. If I may be permitted to hazard a conjecture based upon what I have seen, I should suggest that the process is about as follows. Sudden precipitation of an immense body of water takes place at a great elevation, a stratum of intensely cold air being interposed between layers of hot air surcharged with moisture. Great drops or spats of water are formed. These assume the globular form as they fall, and a thin crust of ice is deposited about them, and the freezing goes on rapidly from the outer shell to the core, into which the residuum of air occluded in the mass of water is forced, giving it the white opaque appearance which it possesses. The outer crust is formed of smaller hailstones frozen to the shell, and full of minute air vesicles. The mass, as it falls, rotates about its centre. The pellucid spot on the upper side of the hailstone (I imagine that this represents the upper pole) indicates that in the rapid fall the lower edge penetrating the intensely cold stratum of air is frozen first, and the warmer molecules, in obedience to the laws which control their arrangement, rise in the mass to the upper pole, which, therefore, in a number of cases has an incomplete crust or outer envelope. The fall of the larger mass, being necessarily more rapid than that of the smaller masses about it, the hailstone, in its descent, gathers to itself in its downward rush the lesser hailstones which it meets in its course."

Mr. R. N. Clark, of Pittsburgh, found certain partly crushed and melting hailstones, which fell in the business portion of the city, to consist of smaller rounded stones, one quarter to three eighths of an inch in diameter, in the midst of a snowy slush.

The examples which have been given show that, with a general similarity of size and structure, these hailstones possessed considerable individuality, suggesting vicissitudes which are hardly compatible with a calm, continuous fall through regularly

and horizontally stratified air. Such variations are precisely those which might be anticipated according to the theory described by Prof. Ferrel, in his "Popular Treatise on the Winds," Art. 274. A strong ascending current, which in the present case need not have exceeded one hundred miles per hour, at a middle altitude, supplies the moisture necessary for the abundant condensation, and at the same time supports the weight of the forming hailstones, carrying up the smaller ones to great altitudes and regions of low temperature, where, presently, falling outside of the limits of strongest uprush, the larger stones descend into the lower rain clouds to be possibly sucked into the ascending column again and again by powerful horizontal inrushing currents at lower levels, and thus coated alternately with snow and with rain, the latter freezing to clear ice at each ascent into the cold upper air.

A figure of a hailstone by Mr. E. E. Robinson, in "Nature," Vol. 40, p. 151, shows many alternations of clear and opaque ice, of various thicknesses, mostly disposed in spherical shells, but in one case, as seen in section, "bounded by a beautifully frilled outline of opaque ice, which imitated in shape the spheroidal state of a drop of water." These undulatory forms are perhaps identical with our mammillated ones, and produced, as suggested by Dr. Holland, by impact and adhesion of small masses of snow or hail to the surface of a heavier and rapidly descending mass.

The smaller hailstones appear to have revolved almost continually, and thus to have received a spherical form; but with increasing size some irregularity of deposition is almost inevitable, and accordingly, the larger stones are usually oblate spheroids. Since a free solid presents its largest section to a resistance, the largest or equatorial circumference of a falling spheroid must become horizontal under the influence of gravity, and at the same time, if cold, must receive its greatest accessions of condensing material at the rim where the convergence and deflection of air currents is most intense, thus perpetuating the irregularity, unless a collision of unusual force overturns the mass, restoring rotation in some vertical plane.

It remains to be asked what evidence we have of powerful, vertical air-currents in this particular storm.

No observation of anything like a tornado-funnel has been

recorded, although the conditions were favorable for such an occurrence, the storm-area being about 600 miles S. S. E. of a strong centre of low barometric pressure, situated north of Lake Superior, and in an adjoining shallow, but very elongated, trough of nearly normal pressure, stretching from the St. Lawrence Valley to Texas, between high areas central in Nebraska and Georgia. A low fringe of cloud, appearing as if blown back by a wind in opposition to the direction of advance, preceded the storm, and was capped by a structureless and very dark cloud ascending to a great height, and spreading at the edges to an alto-stratus veil. The advance was very slow, on an average 18 miles per hour, or, exceptionally, 30 miles at the highest, and, occasionally, as low as 10 miles per hour. Thunder was in some cases heard at frequent intervals during three hours before the storm arrived.

Dr. Holland, of Pittsburgh, says: —

"The storm was long in brewing. Gradually it became so dark that we were compelled to turn on the electric lights, though the room is well lighted, and it was only a little after the middle of the afternoon. I went to the large window which faces to the north. Very high up in the air was a dark mass of cloud quite uniform in color, and purplish black, looking very much like the dark purple veil of an advancing thunderstorm, but spread out over the upper regions of the sky, covering the entire heavens to the zenith. Below this, appearing above the high brow of the hill, were masses of torn and ragged clouds arranged apparently in great laminæ or folds, with torn and ragged outer edges, reflecting the light from the eastern and southern portions of the heavens, which were covered with thinner masses of cumulo-stratus cloud, with here and there spots, which, before the storm broke, showed the bright blue of the open sky. These great folds differed from the folds of a thunderstorm, which appear ordinarily above and in advance of what I call the veil of the storm, composed of the down-rushing rain. In ordinary storms these clouds show as a fringe, forming a long line across the sky, or bowed out in the middle, as they are propelled by the rush of the wind moving parallel to the surface of the earth. The clouds on this occasion seemed to be moving in a rotary manner away from the direction in which the storm was slowly advancing, and the folds resembled great

vaporous spokes of a wheel, the centre of which was advancing towards the point occupied by the observer, while the motion of the masses was in an opposite direction. I was impressed at the moment by this peculiar appearance of the clouds, and even more by the tremendous mass of dark cloud hanging high above this lower moving assemblage of clouds, and apparently motionless, or very sluggish in its movement."

Whether this dark mass of cloud concealed a tornado, which remained in the upper air, can only be conjectured. Rolling masses of dense cloud apparently moving in different directions were reported. The general direction of the clouds along the advancing edge of the storm was from the west or southwest, while after the storm was past the wind was northerly, the movement of the combined cloud-belt being from the northwest.

At Pittsburgh, as reported by Mr. O. D. Stewart, Local Forecast Official, the barometer, which stood at 29.18 inches in the middle of the forenoon, fell gradually to 29.04 inches at 3.45 P. M.,* when hail began to fall. It then rose quite rapidly to 29.14 inches with several very sudden fluctuations of 0.05 to 0.08 inch, remaining unsteady until midnight. (The reduction to sea level is + 0.87 inch.)

Exceptionally heavy rains, during several days preceding the event, had saturated the soil of the entire region over which this storm extended. All of the rivers were in flood, and there was needed only a clear sky and hot sunshine to cover the region with a mantle of hot saturated air.

The Weather Bureau map of 8 A. M. shows a depression of temperature of 12° Fahr. to 22° Fahr. in North Dakota and Minnesota, with a warm wave extending from Virginia and Tennessee to Lake Superior, having a temperature-abnormal, varying from +10° Fahr. to +16° Fahr., and this abnormal temperature was largely increased during the day, until at Pittsburgh from a minimum of 50° Fahr. at 6 A. M., the thermometer rose to 83.5° Fahr. at 2 P. M., falling 18° in five minutes during the descent of the hail at 3.45 P. M., and afterwards slowly recovering some 4° by 10 P. M., the succeeding days being warm.

In Fig. 3 the progress of the advancing edge of the cloud-belt is shown.† At noon it extended through northeast Ohio

* All times are those of the 75th meridian.

† Figures denote rainfall in hundredths of an inch.

to the south of Cleveland, where local observers reported tremendous thunder and some hail. Advancing to the east or southeast, it appears to have lingered over central Ohio, and possibly for a while to have receded; but about 2 P. M. we find the storm stretching in a northeast to southwest direction across northwest Pennsylvania. On approaching the valleys of the lower Allegheny and Ohio, progress seems to have been impeded by the great body of hot and moist air which had to be disposed of. The eastern end of the belt being in a cooler and drier region advanced more rapidly, the line changing front and the nose of the storm swinging around in a curvilinear trajectory, until at nightfall it brought up against the central ridge of the Allegheny Mountains over which the disturbance did not pass, the high barometer to the southeast preventing further progress. At the last reports, the line extended across the middle of West Virginia, parallel with numerous ranges of hills, in a nearly east and west direction; but approaching the Allegheny Mountains it turned sharply to the northeast, following the trend of this range to central Pennsylvania. The nose, or point of greatest inflection of the cloud-belt, passed Johnstown about 5 P. M., and continued in a southerly course, the eastern branch of the storm line pivoting about Johnstown as a centre, passing over the city as many as five times in its oscillations, the first showers advancing from the west and the last three from the southwest, the entire series continuing for five hours. No hail fell at this point, nor in general along the eastern limit of the storm, but in the valleys of the Youghiogheny, Monongahela, lower Allegheny and Ohio rivers, hail was common, varying in size from that of a pea to the largest above recorded. The precipitation was not excessive, 1.6 inches of rain at Greensboro, Pa., being the largest reported, but everywhere the observers comment on the exceptionally threatening aspect of the clouds, and frequently on the violence of the electrical accompaniments.

A few extracts, selected from a large number of replies to a circular of inquiry, will supply the details of the picture.

In northwest Pennsylvania, the storm was not remarkable except for very high wind at Parker, where oil derricks and trees were blown down. The temperature varied from 75° Fahr. in the middle Allegheny valley to 64° Fahr. in the northern

part, and the rainfall correspondingly diminished from 0.3 inch to 0.1 inch, the duration being from two to six hours, with but little thunder, no hail, and slight fall of temperature. In fact, the storm in this region appears to have passed into a slight general rain.

Westward and southward the temperature increased greatly, with corresponding augmentation in the fall of temperature and violence of the storm.

Mr. A. W. Strong, of Linton, on the banks of the Ohio River, at the northeast corner of Jefferson County, Ohio, has given me much information about the conditions in his neighborhood. He says, "Late Friday night and also early Saturday morning (May 20), there was a dense fog here, the temperature Saturday morning being about 57°. The fog lifted about 8 A. M., and with clear sky the temperature rapidly rose, and by noon stood about 85°. There was nothing to indicate an approaching storm until, about 11.30 to 11.45 A. M., clouds were seen in the northwest, which passed here about noon with some heavy thunder, but no rain, although it probably rained about two miles north. I have since heard that in this storm, hail, one inch in diameter, fell at Bayard, 30 miles northwest of here."

About two hours later, or at 2 P. M., "long, somewhat narrow and heavy" clouds were again seen in the west and northwest. The first thunder was heard at 2.20, and from 2.30 to 4.30 rain fell, with dashes of hail at 2.45, 2.55, and 3.05, the thermometer falling from 87° to 63° Fahr. in a very short time. The hail varied from the size of a pea to that of a small shelled hickory nut, some stones being "flat and thin like a one cent piece, but twice as thick, some nearly the size of a quarter. From here to Empire, five miles further down the Ohio, the stones increased in size to one inch or more."

The rain, which was light at this beginning of a north to south stretch of the Ohio River, became much heavier down stream, being 0.86 inch at Wheeling, where there was a fall of temperature of 14° Fahr., from 87° to 73°, and considerable hail. There was a similar increase of rainfall along the southeast and northwest stretch of the river in the direction of Pittsburgh, where the precipitation was 1.08 inch at Davis Island dam, and 1.04 inch at the Pittsburgh Weather Station. Belts of hail seemed to follow the river. Stations five miles north of the river had

little or no hail. Two miles from the river bank, stones of a half inch were common, but the "great hail" was usually within this two-mile limit, somewhat local in its distribution, not passing into the smaller hail by gentle graduations, but with very sharply defined limits, as determined by the areas of great destruction. In the city of Pittsburgh, at the junction of three great river valleys, it was nearly calm while the hail fell, but two miles north the balls of ice were driven with great effect against all north-northwest exposures by a wind of probably 25 miles per hour.

At the extreme eastern limit of the storm, Johnstown, and Stoyestown, Pa., there was no hail, but "inky black" clouds, and a fall of temperature of 24°, from 86° to 62° F.

Mr. E. C. Lorentz, of Johnstown, writes that the forenoon was "clear. Cirrus appeared about 2 P. M.. At 4 P. M. it looked very threatening, clouds scarcely moving and seemingly very low. Great clouds of dust from the street. Principal storm began at 5 P. M. Considerable lightning and loud thundering. Rain (at times very light) fell constantly between 5 P. M. and 10 P. M."

Hail from ½ inch to ¾ inch fell at Freeport, in the Allegheny valley, but only small stones occurred further north.

The Youghiogheny valley suffered from hail as large as ¾ inch as far up as Confluence, Pa.

Smaller stones, seldom larger than "peas" or "marbles," were commonly reported throughout the valley of the Monongahela.

The observers in this district all agree as to the exceptional darkness of the clouds. "They were peculiar in color, inky in blackness, appearing to have a dazzling light behind, the most frightful I ever saw," writes Mr. Chas. R. Johnson, of Morgantown, W. Va.

Toward the southern limits of the storm, as the highlands were approached, and after the regions of great humidity had been left behind, the hail diminished, but the electrical phenomena became more pronounced. "Unusually severe and almost continuous thunder" is reported. Dr. M. H. Proudfoot, of Rowlesburgh, W. Va., writes that "thunder was first heard at 9 P. M. Rain began at 9.30 and ended at 11.15 P. M. Direction of wind during storm from the west. Velocity about fifty miles

an hour. The storm cloud advanced from the west. There were very few hailstones. The temperature before the storm was 87°, after, about 68°. It was the worst storm in this section known for years. The display of electricity was simply phenomenal."

It appears from what has preceded that this storm belongs to Prof. Davis' second class of thunderstorms, "which spring up in the warm southerly winds, southeast of a cyclonic centre, and whose convectional overturning is therefore due in part to imported heat." * The fall of temperature seems to have been due to the large body of hail, and to the downrush of air from the upper atmosphere, which the hail brought with it in its final fall, rather than to horizontal inrush from a neighboring cold area. While a moderate circulatory velocity was maintained in a horizontal plane about a very elongated axis, it is probable that the chief circulation was a vertical one, the hail descending in the rear of a vertical uprush, which left in its wake a dense sheet of alto-stratus from which rain continued to fall at most stations in a quiet manner for some hours after the more exciting episode. The edge of the disturbance had meanwhile advanced anywhere from fifty to one hundred miles, so that the storm may be defined as a wave front of vigorous convectional overturning from two hundred to three hundred miles long, advancing into a clear, hot, and moist atmosphere, with strong vertical inequality of temperature, and leaving behind it a high sheet of rain cloud in a quiescent atmosphere to precipitate itself slowly in rain, or to dissolve, as the local conditions might determine.

Thunder showers accompanied by heavy rain were reported from Huntingdon, Pa., in the evening. These, however, do not appear to have been directly connected with the particular storm which we are endeavoring to trace, although, no doubt, originating in the same general conditions.

The two photographic reproductions, Figs. 4 and 5, show the destruction wrought by the hail in Allegheny's fine Public Conservatory, and the appearance and distribution of the freshly fallen hailstones upon a lawn. They were taken by Mr. J. A. Brashear, of Allegheny, and are more eloquent than words.

ALLEGHENY OBSERVATORY, July, 1893.

* Annals of Harvard College Observatory, Vol. 21, p. 132.

## ANALYSIS OF THE CAUSES OF RAINFALL WITH SPECIAL RELATION TO SURFACE CONDITIONS.*

GEORGE E. CURTIS.

THE possibility of changing the amount of rainfall by human agency has in late years received a great deal of popular attention, and an undercurrent of hypothesis with regard to it has gradually set in, which itself has stimulated scientific inquiry. The question has been directed most frequently to the effect of forests and to the special inquiry as to whether forestation increases and deforestation decreases the rainfall.

In this inquiry the statistical method has been extensively employed, and all the existing rainfall data bearing upon the question and some that are entirely irrelevant have been discussed. Special rainfall observations have also been inaugurated for the purpose of determining the relation of forests to rainfall. Without giving a *résumé* of these various investigations it is sufficient to state that no definitive conclusion has as yet been derived from them. The one conclusion which the statistical results seem to yield is that, if forests affect the rainfall, the amount of effect has, in most cases, not been greater than the amount of probable error in the observations themselves, and, therefore, the statistics give no assurance that the effect is not an error of observation. This, however, is a result of importance, for it serves to delimit, for the regions to which the statistics apply, a maximum value which the supposed effect of forests has not exceeded. This maximum value is, in most cases, but a small fraction of the total rainfall, an amount too small to be of any considerable hydrographic or economic importance. Another reason for the unsatisfactory results of the statistical investigations is, that they have seldom been combined with a rational explanation of the process by which a change in the rainfall may be brought about, and, consequently, they have not helped to clarify the misty meteorological conceptions which are current thereon. To do this is the object of this paper.

* Reprinted from U. S. Department of Agriculture, Forestry Division, Bulletin No. 7, pages 187–191.

If in any region the rainfall is increased by a forest cover it must be brought about either (1) by an increase in evaporation, which increase must be precipitated over the same region, or (2) by a diversion to the forest area of rain that would otherwise fall in some other locality.

Let us now analyze the causes and conditions of rainfall, so far as they are now understood, and see if the results will not materially aid us in determining how far and in what cases each of these methods of increasing the rainfall can be operative and efficient. I say in what cases, for one of the most important objects of this analysis will be to make clear that an effect that obtains in one climate may be entirely absent in another. Ideas as to the causes of rain have been greatly simplified by recent studies, and many different conditions that are generally enumerated by the books as productive of rain have been set aside.

The following quotation from a recent paper by Blanford sets forth with great clearness the opinions that meteorologists are now adopting: —

"As a result of a long study of the rainfall of India, and perhaps no country affords greater advantages for the purpose, I have become convinced that dynamic cooling, if not the sole cause of rain, is at all events the only cause of any importance, and that all the other causes so frequently appealed to in popular literature on the subject, such as the intermingling of warm and cold air, contact with cold mountain slopes, etc., are either inoperative or relatively insignificant." ("Nature," xxxix.,583.)

The ascensional movement of the air requisite to dynamic cooling may be brought about by three different processes: (1) by convective currents; (2) by hills and mountains; (3) by cyclonic circulation; and I classify rainfall as *convective*, *orographic*, or *cyclonic*, according as it is due to the first, second, or third of these causes of ascensional movement. Of course in some cases all of these may be operative at the same time, but for the purposes of analysis they will be separately considered.

In a region of purely *convective* rainfall, the circulation is primarily vertical, and the moisture evaporated is largely precipitated before being carried away by horizontal currents. Therefore an increased evaporation will be followed by an increased rainfall. Consequently any change in surface condition which increases or diminishes the evaporation will, in such a

climate, be followed by a corresponding increase or decrease in precipitation.

In the case of *orographic* rainfall, currents that are essentially horizontal are forced to become locally ascending. The moisture evaporated in the region lying in the path of the current is partially or entirely precipitated over the region where the ascensional movement is developed. Consequently an increased evaporation will, to a greater or less extent, be restored to the basin by an increased precipitation. The extent to which this will take place, that is, the proportion of the increase of moisture that will be returned to the basin, will depend on the extent and height of the mountains and the relative frequency of the orographic rain-bearing winds. For example, if these winds prevail only half of the time, only half of an increased evaporation can, in general, be precipitated as orographic rainfall. It seems quite possible, therefore, with observations showing the amount of change in the evaporation and with observations of the relative frequency of wind direction, to compute with considerable closeness a maximum value which the resulting change in rainfall cannot exceed.

The second point to be considered with respect to orographic rainfall is whether a forested hill or mountain can originate or divert to itself moisture-laden currents, which, without a forest cover, would not exist or would give their rain to other localities. Mountains, by means of their heated surfaces, develop upward currents, but when they are forest-covered the observations presented by Mr. Fernow in this bulletin show that the air is less heated than when the surface is bare. Forests will, therefore, tend to diminish rather than to augment the diurnal currents which set in upwards toward the summit, and which, by dynamic cooling, precipitate their moisture. Likewise, there is lacking any sufficient reason to suppose that lateral currents moving in some other direction will more likely be deflected from their course and diverted toward this mountain summit because it is covered with forest and hence relatively cool.

The general class called *cyclonic* rainfall includes a great variety of rain types related to a cyclonic circulation, some of which are as yet by no means well understood.

In the ordinary progressive area of low pressure the cyclonic circulation is largely horizontal, but with an upward component.

This upward component produces the usual rainfall of our cyclonic storms. In these storms the horizontal component of the circulation is so large that the moisture evaporated over one region is precipitated over another. Consequently in regions where rainfall is of this type, an increased evaporation in any region will not be followed by an increased rainfall in that same locality.

In local thunderstorms we have a type of rain related to a cyclonic circulation in which the vertical component often becomes very large, as compared with the horizontal component. This predominating vertical component is due to convection and the accompanying rainfall is to be considered as partly or largely convective. Convection induces and initiates a cyclonic circulation which may continue after the directly convective action has ceased. It becomes desirable, therefore, to separate the directly convective rainfall, whose amount can be locally increased by increase of evaporation, from the cyclonic rainfall whose amount cannot be so increased. An approximate separation can be made when the diurnal periodicity of rain is known; for an excess of rainfall during the afternoon hours may be classed as convective.

Secondly, we have to consider the question as to whether cyclonic rain storms can be deflected from one course to another by difference in surface conditions. Evidently great areas of low pressure cannot be affected and so the question is restricted to local cyclonic storms of small area. With respect to these the question is to be answered in the affirmative, for it is entirely in accord with physical principles to suppose that small cyclonic storms, areas of clouds and disturbance and other unsettled masses of air with a progressive motion, will tend to follow paths of high humidity and high temperature, lines of atmospheric weakness which all disturbances will seek, just as seismic disturbances follow lines of weakness in the earth's crust.

Whether the air over a forested area as compared with a neighboring unforested area constitues such a preferable storm path is a question to which a dogmatic answer cannot now be given. As shown by observation, the absolute humidity is in general higher over the forest and the temperature lower than over adjacent open spaces. These are apparently con-

flicting conditions — one decreasing, the other increasing, the relative density and stability of the forest air. It seems hardly probable that the resultant will have any quantitative importance. However, the investigation of the question is a fruitful direction of meteorological inquiry.

The practical point here to be emphasized is that it is not enough to say that the air over a forest is more humid and that therefore there will probably be more rainfall. The increased humidity will be quite ineffective unless this moist air can be cooled dynamically over the region itself, and thus condensed and precipitated. This is a necessary additional condition, and the evidence that this will occur in any relative high degree, either by convection currents or by deflected storm paths is yet lacking.

*Climatic Illustrations:* — The equatorial rain belt is the most prominent region with almost exclusively convective rainfall. The Brazilian forest region, the Aruwhimi district of central Africa, the Malaysian Archipelago, and the valley of Upper Assam in India are in or near this belt. They have light winds, and the moisture evaporated from the surface is precipitated before being carried to any considerable distance by horizontal currents. Under these conditions an increase or decrease in the evaporation will be followed by an increase or decrease in rainfall. But they are the very regions where any material change in the evaporation appears to be most difficult to effect. The evaporation is large. Blanford estimated that for the Aruwhimi district probably over half of the rainfall is due to the direct restoration of the moisture evaporated. The surface is maintained in a continual state of saturation, and evaporation proceeds uninterruptedly at a nearly uniform rate. How will deforestation affect this evaporation? In the first place, a cleared surface will have a higher temperature and the winds will have freer play, both of which results will conduce to increase the evaporation, and, consequently, also to increase the rainfall. The wind effect, however, will be small because the regions under consideration are in the belt of calms. On the other hand, if deforestation should initially induce a materially increased run-off, so that there should be left much less water to evaporate, the evaporation would be diminished, and consequently also the rainfall would be diminished; and when the

rainfall had fallen off the streams would fall to their previous quantity of discharge. We have, therefore, a possibility of two opposite tendencies acting at the same time — one to increase the rainfall, the other to decrease it. The question as to which will preponderate, and to what extent, is apparently a question to be ascertained for each separate district, for the result in one region may be quite different from what it will be in another. Furthermore, this analysis suggests that a very promising method of investigating the effect of forestation and deforestation in districts of convective rainfall appears to be not by observations of rainfall, but by comparative observations of the discharge of the streams. Finally, in the equatorial belt, which is the only portion of the world having an almost exclusively vertical circulation, the rainfall is so much in excess of the needs of vegetation that its possible modification has not the same economic importance as in higher latitudes. There is no motive to increase it, and if diminished, no detriment would result.

Bordering on each side of the equatorial belt are the regions of the trades, which, over the ocean, are almost rainless ; but over intercepting land areas, such as Central America and the Antilles, considerable rainfall occurs. This is frequently difficult to analyze, but it is largely convective and in hilly regions partly orographic. The seasonal distribution shows that the rainfall is intimately related to the annual oscillation of the limits of the trade wind, and that the rainy season requires a special explanation. With the exception of the well-known tropical cyclones of the seas, the distribution of pressure over the trade region is unfavorable to the development of a cyclonic circulation, and consequently cyclonic rainfall is seldom presented. It is easily seen that the application of this very general statement to the question of the effect of surface conditions requires us to consider some special individual locality. Let us take the island of Barbados. This island is 21 miles long, 14 miles across its widest part, and lies in latitude 13° N., longitude 59° 37′ W. Its interior is hilly and rises at points to over a thousand feet in height. From an extended series of rainfall records carried on by Governor Rawson the average rainfall on the coast is found to be 50 inches, and rising 64 inches on the windward side and in the central highlands. During three-

fourths of the year the northeast trade wind prevails and the rain comes from that quarter. In October, when the southern limit of the trade reaches the island, the wind turns to the west and the heaviest rains occur, making it the wet season. The distribution of rain over the island, both with the trade wind and the west wind, shows that the rainfall is partly orographic, but probably the largest part of it must be considered as convective. On account of the smallness of the island and the prevailing fresh winds, practically all of the moisture thus precipitated on the island comes from the ocean, and the moisture evaporated from the island itself is carried away to sea. When the island was covered with forests the convective action of the island could not have been greater than at present, because its temperature would have been lower, and if a greater evaporation took place there no appreciable amount of the additional vapor could be precipitated on the island itself. We have every reason, therefore, to conclude that destruction of forests or any other surface change in Barbados is powerless to sensibly increase or decrease its rainfall.

Passing from the region of trades, we reach latitudes favorable to cyclonic development. Here convective and cyclonic action are frequently combined. In the warmer latitudes and in the summer season, the equilibrium of the atmosphere becomes unstable and convection currents are set up which induce an incipient cyclonic circulation. Then there is a combined convective and cyclonic rainfall. As we go northward the direct convective feature of the rainfall becomes less prominent, and the purely cyclonic rainfall predominates. Over the whole region orographic rainfall is added to the other two classes when hills or mountains are situated in the path of moisture-laden currents. With this general statement the further examination of the effect of surface conditions on the rainfall in middle latitudes must be applied to concrete cases.

In the United States the Great Plains region of Kansas, Nebraska, and the Dakotas is that for which a variation in rainfall has most often been claimed or anticipated. Many settlers believe that the so-called "rain-belt" is moving rapidly westward with the extension of cultivation and settlement.

The single condition favorable to such an increase of rainfall consists in the steadier and larger evaporation which no doubt,

takes place over the cultivated area, but the other conditions necessary to condense and precipitate this moisture over the same region are largely absent. There are no hills or mountains to produce orographic rainfall, and without these barriers the high winds constantly carry away the moisture evaporated from the surface and precipitate it far to the eastward. Hence, not only is the increased moisture in the air but a small fraction of the total rainfall, but also only a small portion of this is gathered into convective or cyclonic currents, and restored again by them to the prairie soil. Evidently a small amount must be thus restored in every summer rain and the total rainfall increased thereby, but quantitatively this must be very small.

There is one region deficient in rainfall and water supply for which claims in behalf of an actual or possible increase of rainfall due to human agency are less often made, but which the preceding analysis leads me to believe would not be unreasonable to anticipate. I refer to the San Joaquin valley of California. This valley is flanked by the Coast Range on the west and by the Sierras on the east. The moisture evaporated from the surface cannot escape from the basin, but will be largely precipitated either over the valley or on the sides of the adjacent mountains which constitute its watershed. If, therefore, the increase in irrigation and in the extent of cultivated area produces a material increase in the evaporation, it seems reasonable to expect that this moisture will be restored by an increased rainfall in the valley and on the adjacent mountain sides. One consideration only would appear to retard and diminish this effect. The inclosure of the valley prevents that rapid indraft of air which renders possible a rapid vertical circulation. Thus the activity of the whole process is rendered sluggish and the total amount of moisture passing through the cycle from evaporation to rainfall is smaller than with a more parid circulation.

In the manner here outlined the possibility of a variation of rainfall may be investigated for any region, and with sufficient meteorological data, even quantitative values may be computed. The general result indicated by the analysis of the physical processes involved, as well as by the statistical data so far collected, is, that the margin of such possible change is very small. In most cases it cannot exceed a small per cent, and

in other cases it cannot occur at all. It appears, therefore, that in the estimation of the importance and value of forests, a disproportionate and undue amount of emphasis has been popularly given to such an influence

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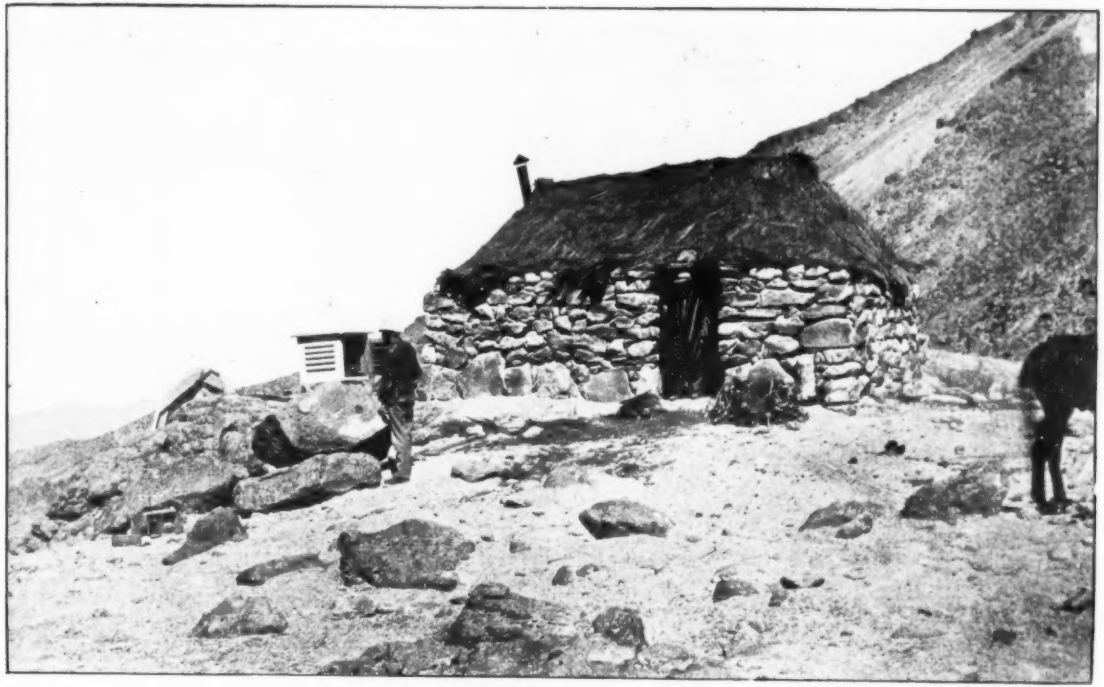
## THE HIGHEST METEOROLOGICAL STATION IN THE WORLD.

A. LAWRENCE ROTCH.

BY the will of Mr. Uriah A. Boyden, a considerable sum of money was left in 1887 to Harvard College Observatory to aid in the establishment of an observatory "at such an elevation as to be free, so far as practicable, from the impediments to accurate observation which occur in the observatories now existing, owing to atmospheric influences." Preliminary stations were accordingly established in Colorado and in California, provided with meteorological and astronomical instruments to test the meteorological as affecting the visual conditions. From these observations it was concluded that the selection of a proper site was by no means a question of elevation alone, and it was thought desirable, from theoretical considerations, to secure a location within the tropics.

An expedition was accordingly sent to South America, where a station on Mt. Harvard, near Lima, Peru, at an elevation of 6,600 feet, was occupied for a year, and other sites further south were examined by the Messrs. Bailey. Owing to the remarkable clearness and steadiness of the air at Arequipa, Peru, it was finally decided to locate a permanent station there, and, under the direction of Prof. W. H. Pickering, land was purchased outside this city and the observatory buildings were erected in 1891. The city of Arequipa is situated above a desert about 80 miles from the Pacific Ocean, in a little oasis formed by a river valley at the foot of the Cordillera. The observatory is built upon the crest of a hill overlooking this valley, about 400 feet above the city and 8,050 feet above the sea. It stands approximately in 16° 22′ south latitude and in 71° 22′ west longitude. Eastward, the extinct volcano of Pichupichu rises to a height of 18,600 feet; northeast and ten miles distant is the quiescent volcano of the Misti, 19,200 feet in

THE CHARCHANI STATION FROM THE NORTH.



THE CHARCHANI STATION FROM THE NORTH.

altitude, and twelve miles north rises Charchani, 20,000 feet high, which is always snow-capped.

The meteorological station, forming the subject of the article, is situated on the latter mountain just below the permanent snow-line. Southeast of and about 3,400 feet below the summit is a *cirque* forming a plateau less than half a mile square which drops several hundred feet in a precipice on the south. Near the brink, at an elevation of 16,650 feet above the sea, is the meteorological station. The instruments are contained in a small louvred shelter, twenty-two inches square, placed on a rock, and comprise the "exposed" and maximum and minimum thermometers of the U. S. Signal Service pattern, a self-recording aneroid barometer, and two self-recording thermometers, all of the well-known Richard *frères*' construction. The record cylinders revolve in rather more than seven days, but as the clock movements operate during ten or twelve days, records for this length of time can be obtained, since as the cylinders do not turn in an even number of days the diurnal variations of pressure and temperature during the second week are not superposed upon those of the first week. Near the shelter has been erected a stone hut where the person who ascends the mountain to care for the instruments can spend the night, if necessary. The ascent of 8,600 feet from the observatory can be made by mule in about eight hours; and though it is intended to have one of the assistants visit the station each four weeks, regular ascents have not been practicable; consequently, during the year the station has been equipped, only portions of ten months' records could have been obtained, and unforeseen stoppages of the self-recording instruments have further reduced the quantity of complete records to eight. The automatic traces of atmospheric pressure and air temperature are controlled by a mercurial barometer carried up by the observer and by readings of the "exposed" and the maximum and minimum thermometers, the two latter showing the extremes of temperature which have occurred since the last visit. The distance in an air-line from the station to the observatory is about eleven miles, and such is the transparence of the air that on a large white disk, which has been placed on the edge of the plateau, a black spot one inch in diameter can be seen with the thirteen-inch telescope at the observatory.

The meteorological equipment of the observatory is quite complete; and besides the ordinary instruments for direct observations there are the self-recording barometer and thermometer, of Richard *frères*, an anemograph of the Signal Service type, and photographic sunshine recorders of the form devised by Prof. Pickering. Direct observations three times a day, at 8 A. M., 2 and 8 P. M., with frequent night observations at 2 A. M., have been made during two years but have not been reduced. The results of the observations at both stations will be published later in the "Annals of Harvard College Observatory," and their discussion will no doubt add greatly to our knowledge of mountain meteorology. Anything more than a brief summary of some of the most salient features would, therefore, be out of place here. From data for the year 1891–1892, cited by Prof. Pickering in "Astronomy and Astro-Physics," May, 1892, it appears that the atmospheric pressure and air temperature at Arequipa are very uniform throughout the year. The highest barometer reading was 22.676 inches on Aug. 17, and the lowest, 22.472, on Jan. 19. The maximum thermometer reading, which was exceptionally high, was 79.0° on June 3, and the lowest, 38.5° occurred eight days afterwards. Although the temperature never descended to freezing, yet there are occasional frosts, and in the clear season the intense radiation causes thin ice to form. The clear season begins about the first of April, and continues with scarcely an interruption until the first of November. During January and February, 1892, most of the rain fell, amounting to two or three inches. In February, 1893, four inches fell in a single storm, but this appeared unprecedented and did great damage. The mornings are generally bright throughout the year, most of the rain falling in the afternoon or evening. Excepting during the rainy season, the air is exceedingly dry, relative humidities of thirty-five per cent having been recorded in March, 1893. The wind, as at low elevations, reaches its highest velocity in the middle of the day, and it is generally calm at night. For the year above quoted, the highest velocity, seventeen miles per hour, occurred in December. Soon after sunrise a strong wind blows down from the mountains to the northeast, after which the wind shifts, decreases in velocity, and resumes its normal course.

The diurnal periods of the atmospheric pressure and the air

temperature are interesting on account of the small amplitude of both, and the phases of the former. Taking the barograph records for December, at Mollendo at sea level, at Arequipa (8,050 feet), and at the camp on Charchani (16,650 feet), the respective diurnal amplitudes are 0.1 inch, 0.07 inch, and 0.03 inch. Whereas, at the sea-level station, the chief minimum and maximum occur about 5 P. M. and 11 P. M., respectively, with secondaries at 4 A. M. and 9 A. M.; at Arequipa, the chief minimum occurs about 5 A. M., and the secondary minimum about 4 P. M. The night maximum, which is also the chief one, occurs at about the same hour at both stations; but at Arequipa the secondary day maximum is advanced to about 1 P. M.

Not enough records at the Charchani station have been reduced to determine definitely the pressure period, but there appears to be a double daily maximum and minimum, whose times correspond in general to those at Arequipa. The noon and night maxima have nearly equal intensities, but the morning minimum is deeper than the afternoon one, as at Arequipa. These facts are the more interesting because some preliminary observations by M. Vallot, on the summit of Mont Blanc (altitude 15,780 feet), showed but a single maximum at about 1 P. M., and a single minimum about 4 A. M., with only a tendency towards a secondary minimum late in the afternoon. At Chamounix, in the valley, the diurnal period is nearly the same as at Arequipa, so that the form of the curve at the Charchani station may be partly due to the situation of the instrument in a depression on the flank of the mountain, the topography of a station being known to influence these periods.

As has been stated, the permanent snow line is above the camp on Charchani, but last March, at the close of the warm and wet season, there were two feet of snow on the plateau. Snow covered the ground down to 14,700 feet, while ice formed at night as low as 11,500 feet. On the night of March 9, the temperature of the air, in the shelter at the Charchani camp, fell to 20.5°, while over the snow, radiation lowered it to 14°. The temperatures do not seem to be greatly influenced by the seasons, and the range from January to March, 1893, was from 13° to 46° Fahr. The decrease of temperature in the 8,600 feet of air between the camp and observatory, as deduced from nearly simultaneous observations at 8 P. M. and 8 A. M. on

March 9 and 10, 1893, was one degree for 284 feet in the morning and one degree for 309 feet in the evening, which agrees with similar observations previously made in the tropics. The relative humidity was completely inverted at these times, the evening observations showing 34 per cent on the mountain and 56 per cent at the observatory, while the morning observation gave 56 per cent on the mountain and 36 per cent at the observatory, the changes from nearly complete saturation to great dryness being very sudden at the upper station.

The physiological effects of an ascent to the camp on Charchani, where the atmospheric pressure is reduced to about 16.50 inches, are very marked. This seems to be about the limit to which mules can be driven, and seldom in other places have they been taken so high. Few persons escape the *soroche* or mountain sickness in some of its forms, especially if they stop a night. The effect upon the writer during his eighteen hours' sojourn may be interesting. Though ordinarily sick at lower altitudes, there was here no nausea or severe headache, the usual symptoms of mountain sickness, which may perhaps be attributed to the ascent by mule, without muscular exertion, whereas previous high ascents had generally been on foot. Other symptoms, however, manifested themselves in abnormal excitability and restlessness which made sleep impossible, and by a lapse of memory as well as in a want of sequence of ideas. The appetite remained good, and the writer's physical condition made it probable that he could have climbed higher. After a rest of two hours at the hut, the pulsations of the heart were 115, and the respiration through the lungs 25 per minute. These decreased during the night to 88 and 22, respectively, and the temperature of the blood (measured under the arm) from 98.06° to 97.52°, the normals at Arequipa at night being 80, 21, and 97.16°, respectively.

All the meteorological data would be much more valuable if obtained in the free air upon the summit of Charchani. The establishment of a station 3,400 feet higher, however, is a very difficult undertaking, as two unsuccessful attempts have been made by parties from the observatory to climb the steep and snow-covered slope. A thermometer shelter, intended for the summit station, was carried some distance up on one of these occasions. If a suitable site could be selected on the summit

of Charchani, and self-recording instruments placed there, it seems feasible to engage an intelligent native to ascend the mountain once a month, or oftener, to keep the instruments in operation, since it is known that some natives are less incapacitated by great altitudes than are foreigners. It is possible that this plan may be carried out by the Harvard Observatory, or, if it is found impracticable, a lower and more accessible peak to the west of Charchani may be thus utilized.

The comparatively elevated temperature and small snow-fall, on the high mountains of Peru, offer opportunities for the establishment of loftier meteorological stations than are afforded by any other country, and the establishment of such a summit station by the Harvard Observatory would be the crowning of its remarkable series of stations, extending from Mollendo, on the Pacific coast, along the railroad which crosses the desert of La Joya (4,140 feet), reaches the divide at Vincocaya (14,360 feet), and descends the watershed to Puno on Lake Titicaca (12,540 feet). Another series, differing little in horizontal distance, but relatively greatly separated vertically, for which the observatory at Arequipa and the camp on Charchani already furnish steps, would make it possible to obtain data of the greatest value for the progress of meteorology, which is looking more and more to the study of the upper air for its advance; and for this study the mountain summits furnish the only practical method of obtaining continuous records approximating the conditions prevailing in the free air.

# CURRENT NOTES.

*Meteorological Observations in Labrador.* — The following notes were taken by Mr. W. R. Smith during July, August, and September, 1891, while accompanying the Bowdoin College scientific expedition to Labrador. They were published in the Bulletin of the New England Weather Service for June, 1893: —

"Near the ocean, the influence of the Polar Current with its load of ice is very marked. While the mercury rarely, if ever, reached the freezing point, the nights were always cold and the days could be called warm only during the few hours when the sun was brightest. The temperature and general aspect of the coast weather during the heat of the summer are much like the climate of New England in April. Throughout the entire summer, banks of snow could be found in shaded spots, many of which gave every evidence of being able to last the entire season. In this connection it should be remarked, however, that the inhabitants stated that the snowfall of the preceding winter was remarkably heavy. Fogs were frequent but no more so than on the coasts of Nova Scotia or Newfoundland. All along the coast the vegetation is scant and stunted with little variation in the 400 miles traversed.

"As soon as one goes a few miles inland the influence of the cold water is no longer felt. Instead of April weather we have that of September. The temperature is much higher and the humidity, of course, less. Vegetation is more abundant, though the severity of the winter renders impossible the existence of any but the hardiest species.

"From July to August a trip was made for a distance of 200 miles up the Grand River which empties into Hamilton Inlet, at a point 150 miles from the general coast line. On this trip a more or less systematic series of meteorological observations were made. The temperature was observed three times each day with both the wet and dry bulb thermometers. The lowest temperature observed was 36° on Aug. 6. There were no storms of any length during the time the party was absent, but on three separate occasions it rained for some hours. Showers were frequent and thunderstorms were noted on the 26th, 28th, and 29th of July. On several other occasions showers were experienced which resembled the thundershowers in every respect except they were not accompanied by thunder or lightning. Very little thunder was heard, not more than two peals with any one shower. Some were cold, but none were accompanied by hail. Rainbows were of frequent occurrence and great brilliancy.

"The clouds were principally cumulus (cumulo-stratus and cirro-cumulus); cirro-stratus were seen once or twice preceding rain. The bed of the river

lay for its entire course in a deep valley, consequently the wind always blew up or down stream, so no regular observations of wind direction were taken.

"Auroras were common and far more brilliant than those seen in New England.

"While the climate of Labrador offers many features of interest to the meteorologist, yet it is of such severity as to preclude the possibility of ever developing that region into an agricultural or grazing country. The barrenness of the soil also leads us to the same conclusion. The only possibility of development lies in lumbering or in mining."

*The Oxford, N. C., Tornado of May* 3, 1893.— Bulletin No. 91 c of the North Carolina Agricultural Experiment Station contains an account of a tornado which occurred at Oxford, in that State, on May 3, 1893, written by C. F. von Herrmann, the assistant director of the State Weather Service. On the morning of May 3, there was a general storm of slight intensity central over Georgia, with rain and easterly to southerly winds prevailing in North Carolina. The storm moved northeastward, increasing in intensity, passing just north of Oxford, and being central at Norfolk, Va., at 11 P. M., with a pressure of 29.36 inches. The tornado at Oxford occurred just at the moment when the trough of low pressure passed over that city. It struck the town at three minutes before 5 P. M. It is a noticeable fact that the day was cool, the maximum temperature not exceeding 75°. Just before the passage of the storm the wind died away, and there was heavy rain, amounting to two inches. "At five minutes to five o'clock," notes an observer, "it turned very dark, and about two minutes later there came quite a blow from the southwest, followed by the current that did the damage, which lasted about one and a half minutes, and five minutes afterwards the sun was shining, with but little wind." A moderate thunderstorm prevailed at the time, with vivid lightning. The path of the storm was from southwest to northeast, and its width about 75 feet.

Several of the characteristic tornado effects were noted. The ends of several houses were blown out from the inside, indicating sudden expansion of the air within them; a bridge was carried by the wind in such a direction as indicated a whirling motion contrary to the direction of movement of the hands of a watch; a skipping action of the tornado was noticed, which left some houses in its path uninjured. Yet in spite of these marked characteristics of a tornado, there is no evidence that anyone saw a funnel-shaped cloud. There was also no unusual roar or noise. Wind-storms occurred at about the same time at other places in the State.

*Thermometric Systems.*— "*Ciel et Terre*," for July 1, contains a note on the different thermometer scales, the publication of which was occasioned by the recent action of the Prussian Government making the centigrade thermometer the official standard in Germany. Hitherto the Réaumur thermometer has been chiefly used in that country, this fact being ascribed to the influence of the celebrated meteorologist, Dove, who, although seeing the advantages of a centigrade scale, said to his pupils that after his death they

might do as they liked, but he begged them not to oblige him to change his habits, as he was too old.

Renou in his "*Histoire du Thermomètre*," has said that the English use the scale invented by a Dane, Fahrenheit; the French, that of a Swede, Celsius, and the Germans, that of a Frenchman, Réaumur. Celsius, who did much to perfect thermometers, published, in 1742, some notes on the graduation of his instruments, in which he placed the freezing point at 100° and the boiling point at 0°. His scale, it may be noted, was, therefore, not as is generally supposed, identical with that of the Centigrade thermometer now in use, but resembled it only in having the same number of degrees between the freezing and boiling points. Some persons give the credit of proposing the 100 degree scale to Christin, of the Academy of Fine Arts in Lyons, who, in July, 1743, publicly proposed such a division. The idea of arranging the centigrade scale in its present form, *i. e.*, with the freezing point at 0°, and the boiling point at 100°, seems to have originated with Linnæus. The Réaumur scale, which is now rapidly falling out of use, is divided into 80 degrees between the freezing and boiling points.

*Statistics of Lightning Strokes in Germany.* — Dr. Kassner has recently written a pamphlet * on the statistics of lightning strokes in Germany.

From his tables, based on reports from fire-insurance companies, it appears that in eight years the number of lightning strokes in Germany has increased 72 per cent. In the first period of eight years, 1876–1883, one building out of 6,090 was struck yearly on the average, while in the years 1883–1891, one building out of every 3,870 was struck. The geographical distribution of lightning strokes is shown on a chart, colored in different shades to indicate different degrees of frequency. From this chart it appears as if thunderstorms were more frequent along river valleys than in the intervening country, but it must be remembered that there are often more houses along rivers than elsewhere. Almost one third of all the lightning strokes tabulated occurred in July. Southern Germany has its maximum in June, while Central Germany has its maximum in May.

*Competitive Examination for a Professorship in the Weather Bureau.* — United States Department of Agriculture, Weather Bureau, Washington, D. C., Sept. 9, 1893. The examination will be open to all. Success in practical forecasting will count 75 per cent of the examination. An essay upon "Weather Forecasts, and How to Improve Them" will count 12½ per cent; and an examination on meteorology (text-book, Waldo's "Modern Meteorology") will count 12½ per cent.

Intending competitors must prepare and forward to the Chief of the Bureau an essay, not exceeding 3,000 words, upon "Weather Forecasts, and How to Improve Them." Each essay to be signed by a *nom de plume*, with true name and address in sealed envelope accompanying. These papers

* "Ueber Blitzschläge in Deutschland während der Jahre 1876 bis 1891." Merseburg, 1892. 4°. 32 pp.

must be in the hands of the Chief of the Bureau by Dec. 1, 1893. The judges will be the Chief, the Assistant Chief, and one other. The best ten essays will be selected, and the authors notified to present themselves at this office for competitive test in forecasting, and further examination as to their knowledge of meteorology.

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ERRATUM. — In the review of "Recent Foreign Studies of Thunderstorms in Germany," published in the July number of this JOURNAL, an article on the "Daily Periods of Thunderstorms in Northern Europe," referred to at the bottom of page 113, was credited to Dr. Assmann. The paper in question was written by Dr. Hellmann, and should have been credited to him.

# BIBLIOGRAPHICAL NOTES.

## REPORT OF THE CHIEF OF THE WEATHER BUREAU FOR 1892.

MARK W. HARRINGTON. *Report of the Chief of the Weather Bureau for 1892.* —From the Report of the Secretary of Agriculture for 1892. 8vo. Washington, 1893, pages 551–626, 4 pl.

PROF. HARRINGTON'S second Report as Chief of the Weather Bureau has recently been issued, and shows an encouraging condition as to the work of the Bureau. The percentages of verification of the twenty-four forecasts east of the Rocky Mountains were, for weather, 83.6 per cent; temperature, 81.9 per cent; weather and temperature combined, 82.9 per cent. Since January, 1892, the percentages of forecast verifications have, in addition to the groupings by States and elements heretofore adopted, been determined by classes of forecasts, *i. e.*, predictions of fair, rain, or snow; warmer, cooler, or stationary temperature, have been grouped,and the percentages of verification of each class computed. The results thus obtained show that of the forecasts for fair weather, 88.8 per cent were verified; for rain or snow, 70.5 per cent; 82.8 per cent of the forecasts for warmer or colder were verified, and of the forecasts for stationary temperature, 79.2 per cent were verified.

A remarkable increase in the number of daily weather maps issued at all the stations is noted. On June 30, 1891, the total number of maps issued daily was 3,100; during the six months ending December 31, 1891, over 5,000 copies were issued; and during the year 1892 the number reached 6,800. This is certainly a most encouraging sign of the growing interest of the public in the subject of the daily forecasts, for these maps are distributed with discrimination, where they will be appreciated, and are not scattered broadcast over the country to persons who do not use or appreciate them. The fact that several of the large newspapers over the United States publish fac-simile weather maps every day is a sure sign that their readers are interested in the maps and the forecasts. We hope, before long, to give the readers of this JOURNAL samples of some of the newspaper maps printed by the papers.

State Weather Services are now established over the whole territory of the United States, with the exception of Alaska. Iowa, Maryland, and New Jersey provided, by Legislative enactment, for the maintenance of their services during the year. On July 1, 1892, 1,888 stations received daily weather forecasts by telegraph at the expense of the Weather Bureau.

The particular topic at present under investigation is the rainfall of the United States, which is being discussed under the direction of Lieut. B. M.

Purssell. Other matters needing investigation are stated to be the determination of the best methods for distributing the forecasts widely and intelligently, and the improvement of the forecasts themselves. In conclusion Prof. Harrington says: "I feel called upon to recommend that for the coming year the climatological work be continued under a special appropriation, and that the attention of Congress be called to the pressing need of our being enabled to distribute in adequate and speedy manner our forecasts to agricultural communities not now easily reached; and, finally, that an effort be made to extend our knowledge of atmospheric conditions by observations made at high elevations in the air, either by balloons or otherwise."

The Report contains further a paper on Weather Conditions of the Crop of 1892, prepared by Major H. H. C. Dunwoody, illustrated by four plates, and a report on the State Weather Service Division by Major Dunwoody, containing the annual statements of the directors of the various services.

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